Ore Formation as Primarily a Physical Process: A New Perspective on the Mineral Systems Method

Jon Hronsky

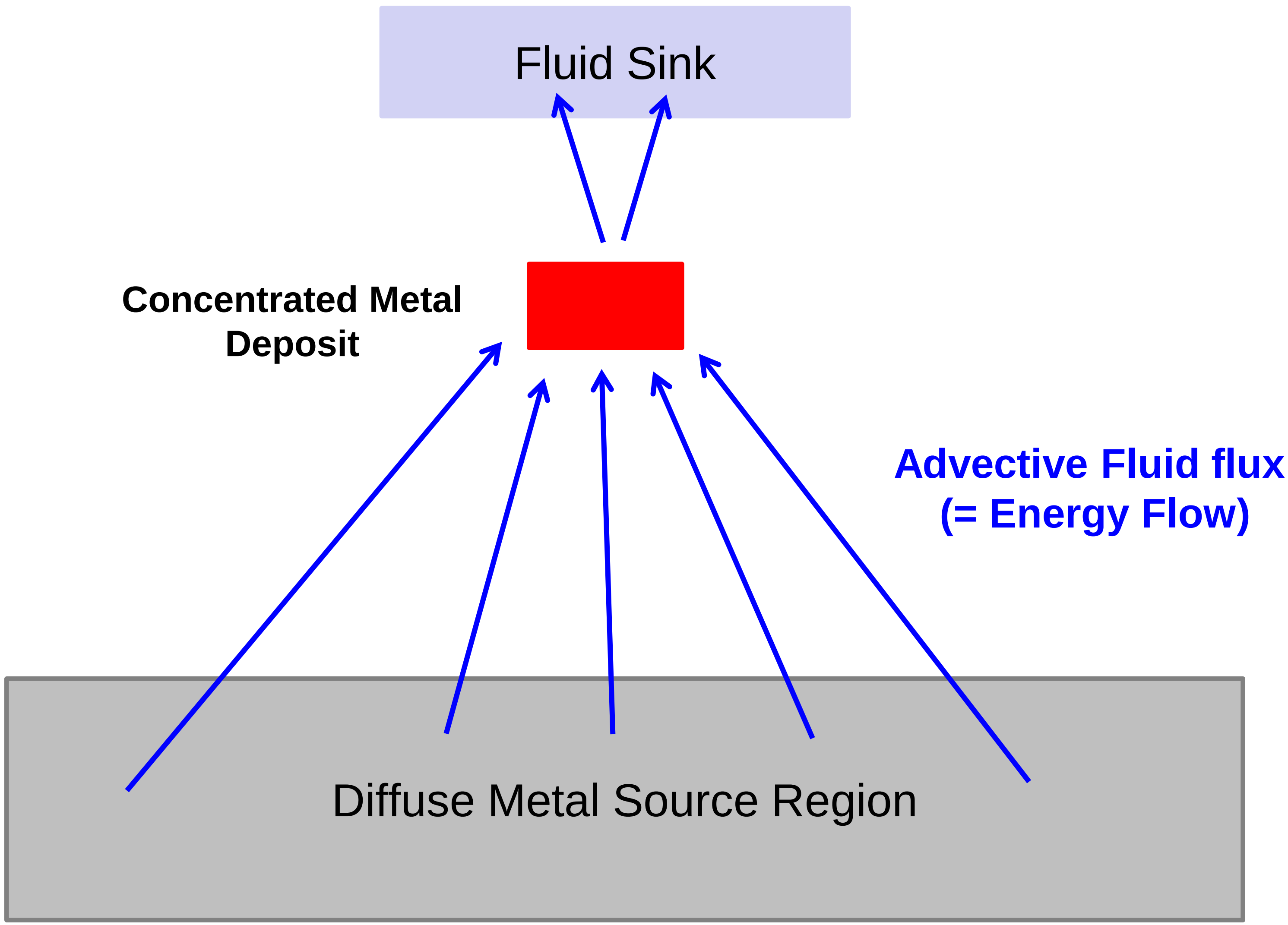
July 5 2010

AESC 2010 Conference

Background Concepts

- Ore formation requires concentrating metal, initially in low abundances in large volumes of rock, into small volumes of rock at high abundances
- The only plausible mechanism is large scale advective fluid flux
- Predicting the location of ore deposits requires understanding the entire system that forms them: the “Mineral System”
- The basic physical processes required for ore formation provide fundamental constraints on viable Mineral Systems
- The Mineral Systems Method is only useful if its components can be mapped to physical rock volumes

Basic Physics of Ore Formation



Key Constraints on Ore Formation from a Physical Perspective

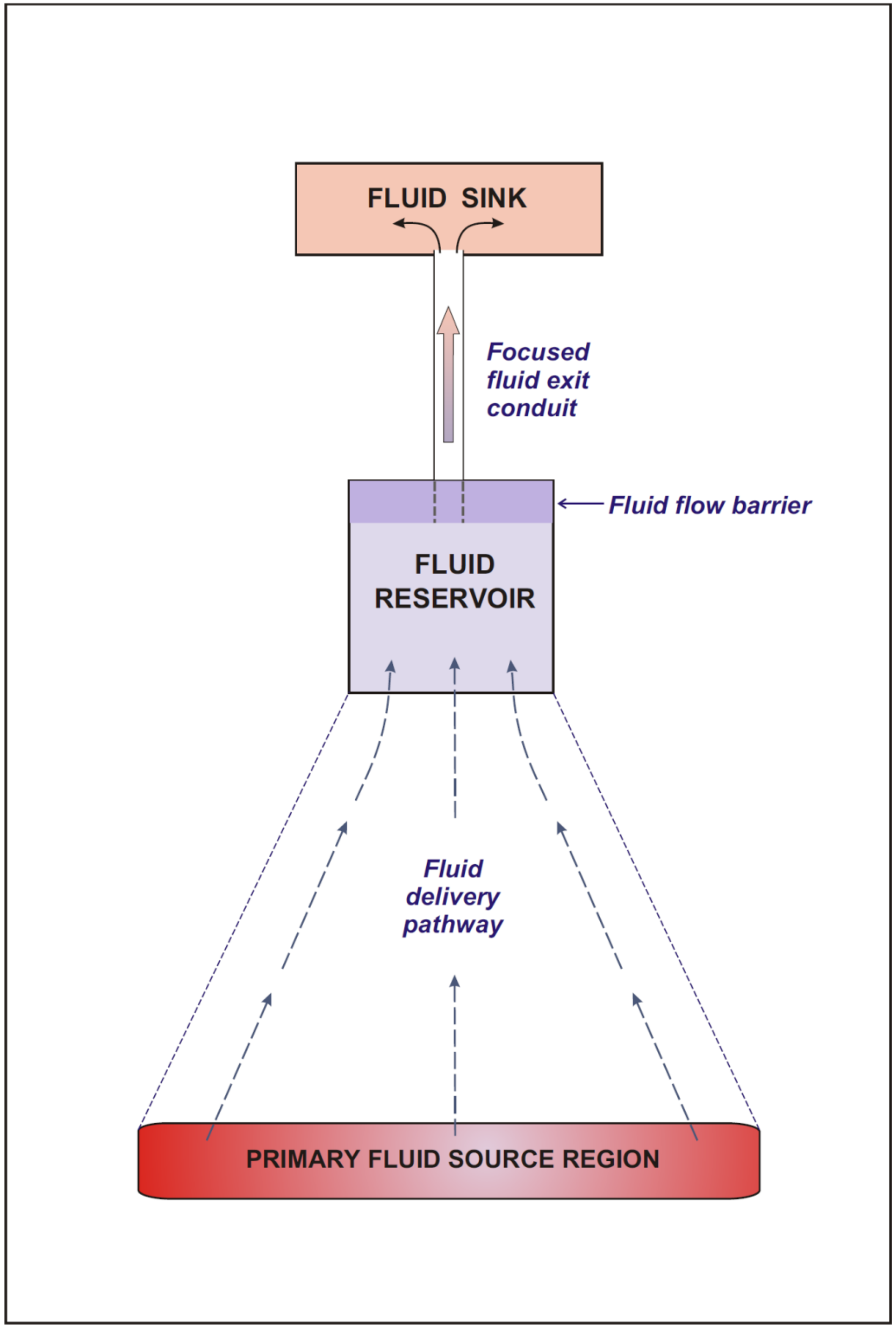
- **Requires availability of large volumes of fluid over *geologically short* periods**

- **Fluid flow systems must mass-balance between source and sink**

- **Fluid flow systems must be highly organised to produce required extreme concentrations: this cannot be the norm because most crustal fluid flow systems do not produce ore**

THE HYPOTHESIS:

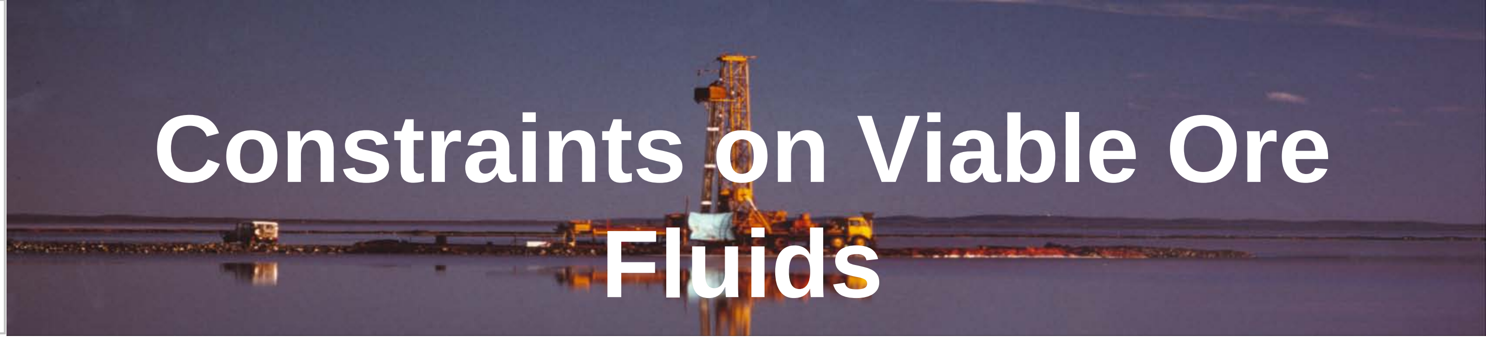
A PHYSICAL PROCESS BASED MINERAL SYSTEM MODEL



Can develop proxies for every component because they all map to a physical rock volume!

WESTERN MINING SERVICES

Constraints on Viable Ore Fluids



- A viable ore fluid must have both:
  - low viscosity
  - be available in large amounts over a geologically short time
- Three Important Low Viscosity Fluids in the Crust (all can transport metals):
  - Water
  - Mafic-Ultramafic Magmas
  - Hydrocarbons
- Only Two Important Primary Fluid Source Regions (Barnicoat, 2008):
  - Hydrosphere (meteoric + ocean)
  - Magmas/Magma source regions

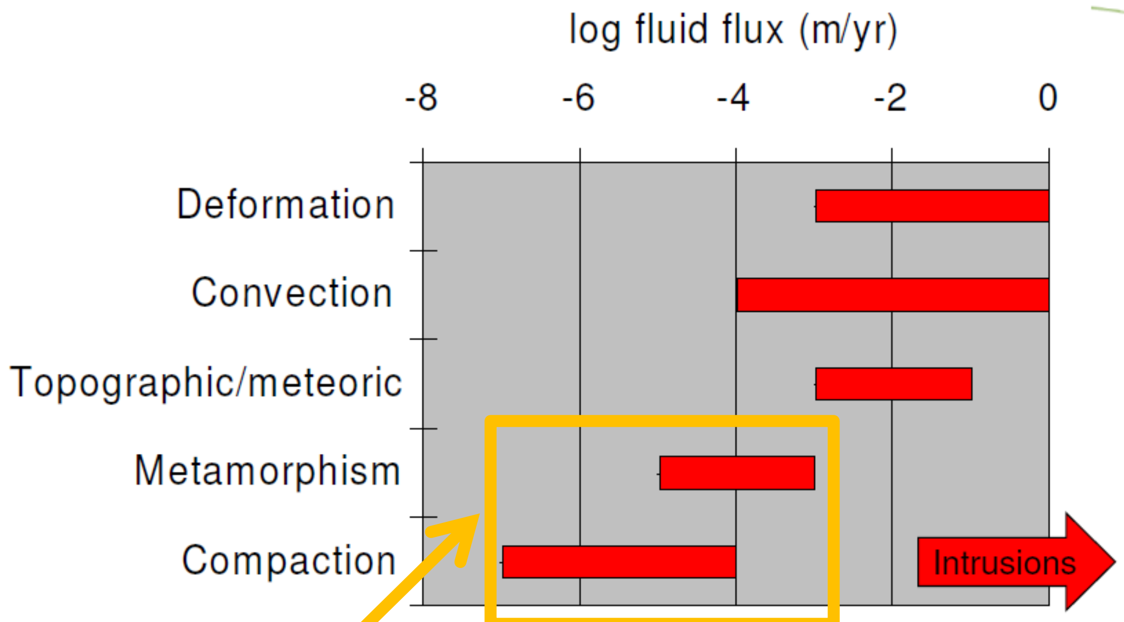
Barnicoat (2008)

Fluid flow drivers: hydraulic potential

Fluid flow rates

predictive mineral discovery

Cooperative Research Centre



There is considerable overlap in flow rates, making it difficult to predict which one will dominate.

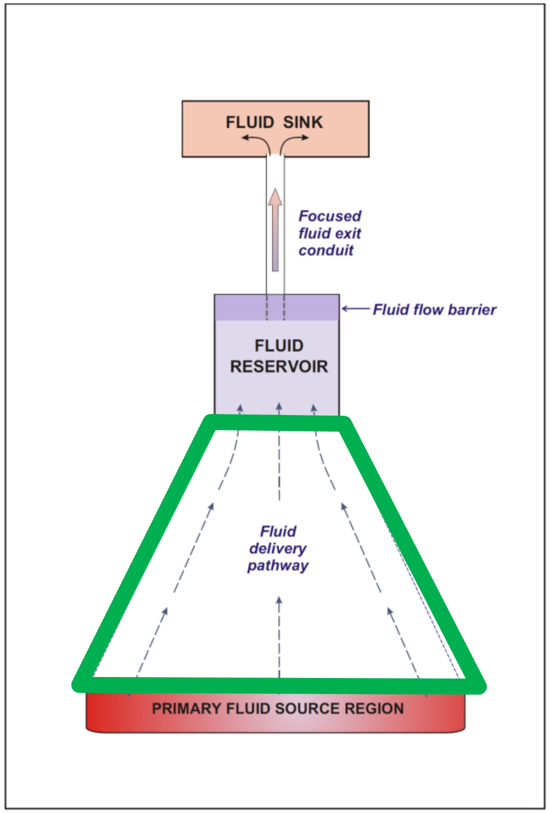
CRC AUSTRALIA

Australian Government

2008 presentation 35

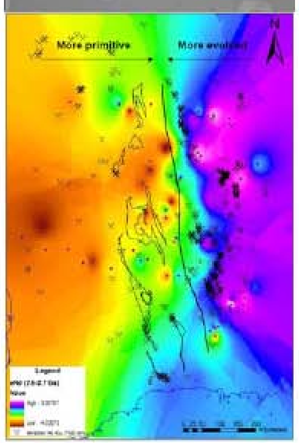
Metamorphism/Basin Dewatering:
Large potential fluid reservoirs but insufficient flux potential – reason why no hydrocarbon generated metal deposits

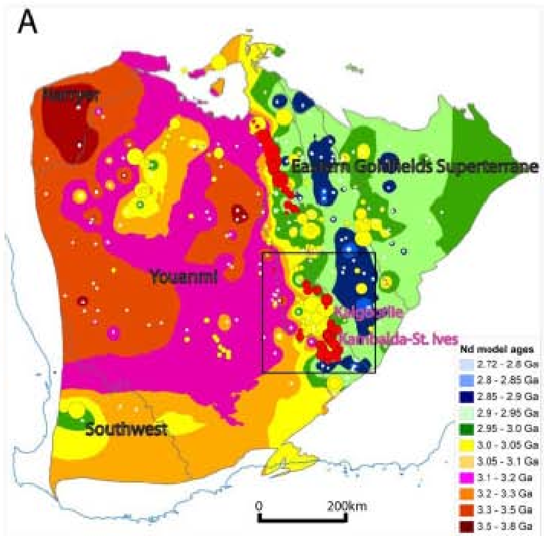
Fluid Delivery Pathways

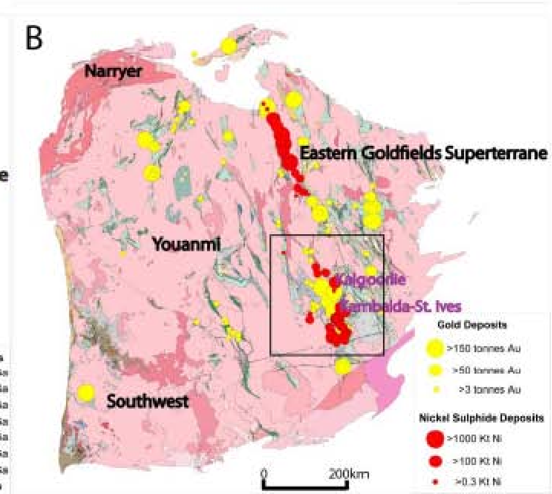


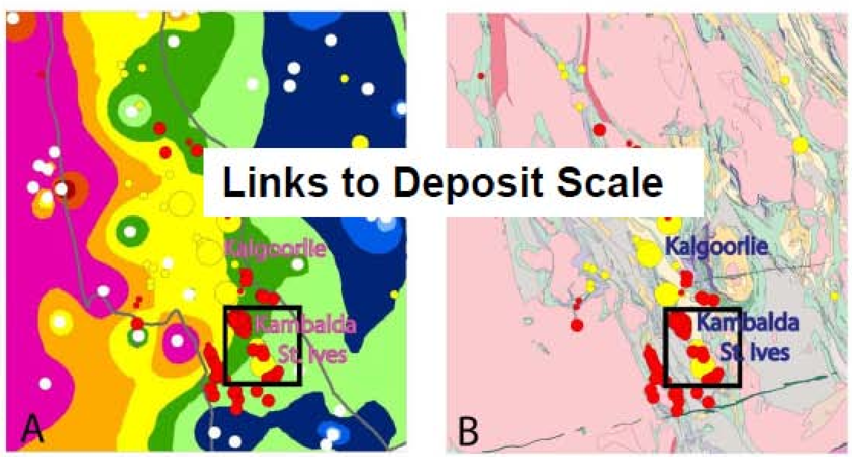
- **Usually very large scale elements**
- **Only two major Fluid Delivery Pathway systems observed:**
  - **Trans-Lithospheric structural zones**
  - **Permeable aquifers in basins**
- **Some mineral systems may use both**

Lithosphere architecture and mineral systems location through time



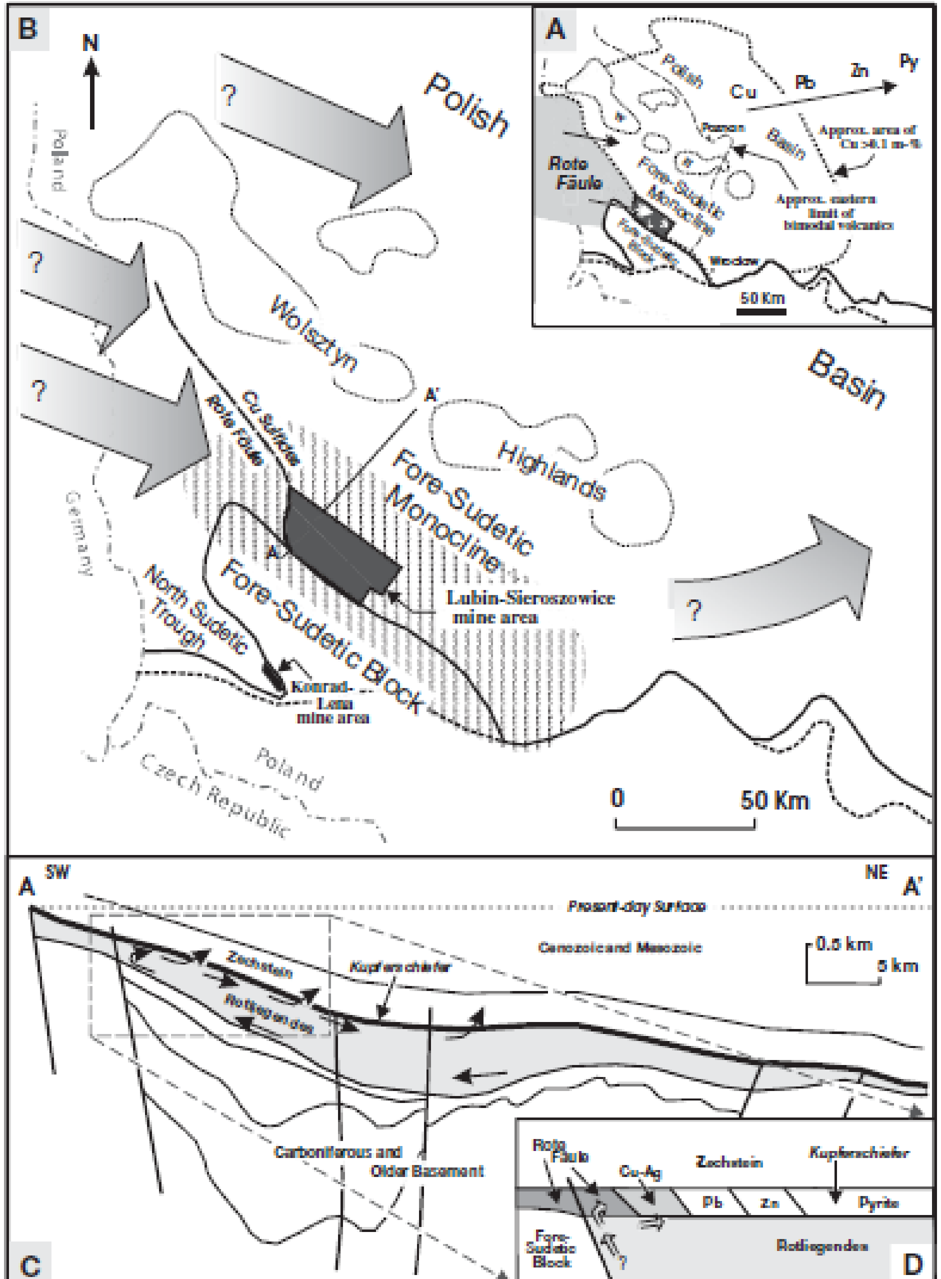




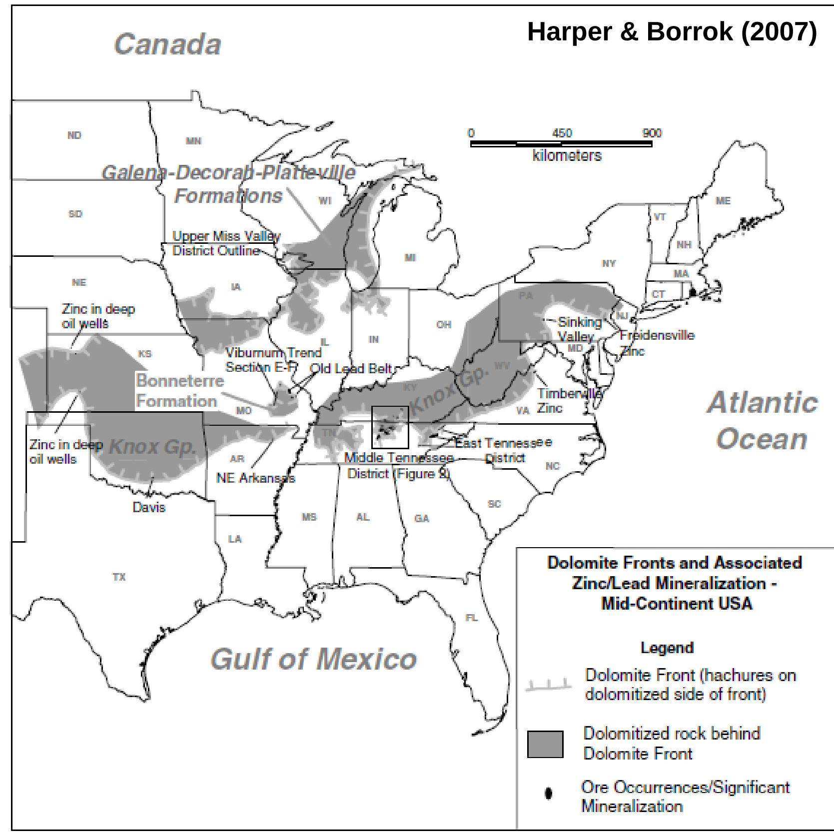


- Isotopic maps as proxies for terrane architecture through time
- Explains stratigraphic variations
- Explains distributions of Ni (red), Au (gold)

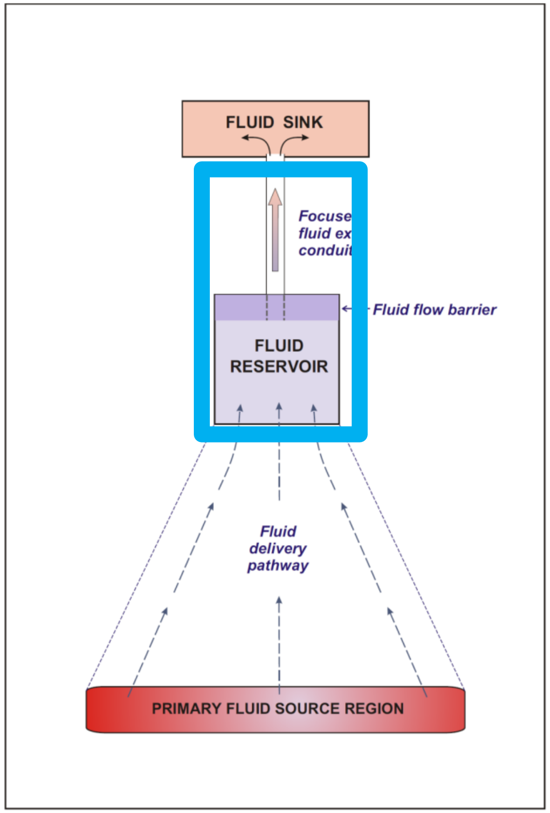
McCuaig et al., 2010


B
N
Polish
Wolsztyn
Basin
Highlands
Fore-Sudetic Monocline
Cu Sulfides
Rote Fäule
Lubin-Sieroszowice mine area
North Sudetic Trough
Fore-Sudetic Block
Konrad-Lena mine area
Poland
Germany
Czech Republic
0
50 Km
A'
A
Polish
Cu
Pb
Zn
Py
Basin
Rote Fäule
Fore-Sudetic Monocline
50 Km
SW
NE
Present-day Surface
Cenozoic and Mesozoic
Zechstein
Kupferschiefer
Rotliegendes
0.5 km
5 km
Carboniferous and Older Basement
C
Rote Fäule
Cu-Ag
Zechstein
Kupferschiefer
Pb
Zn
Pyrite
Fore-Sudetic Block
Rotliegendes
D

Brown (2009)

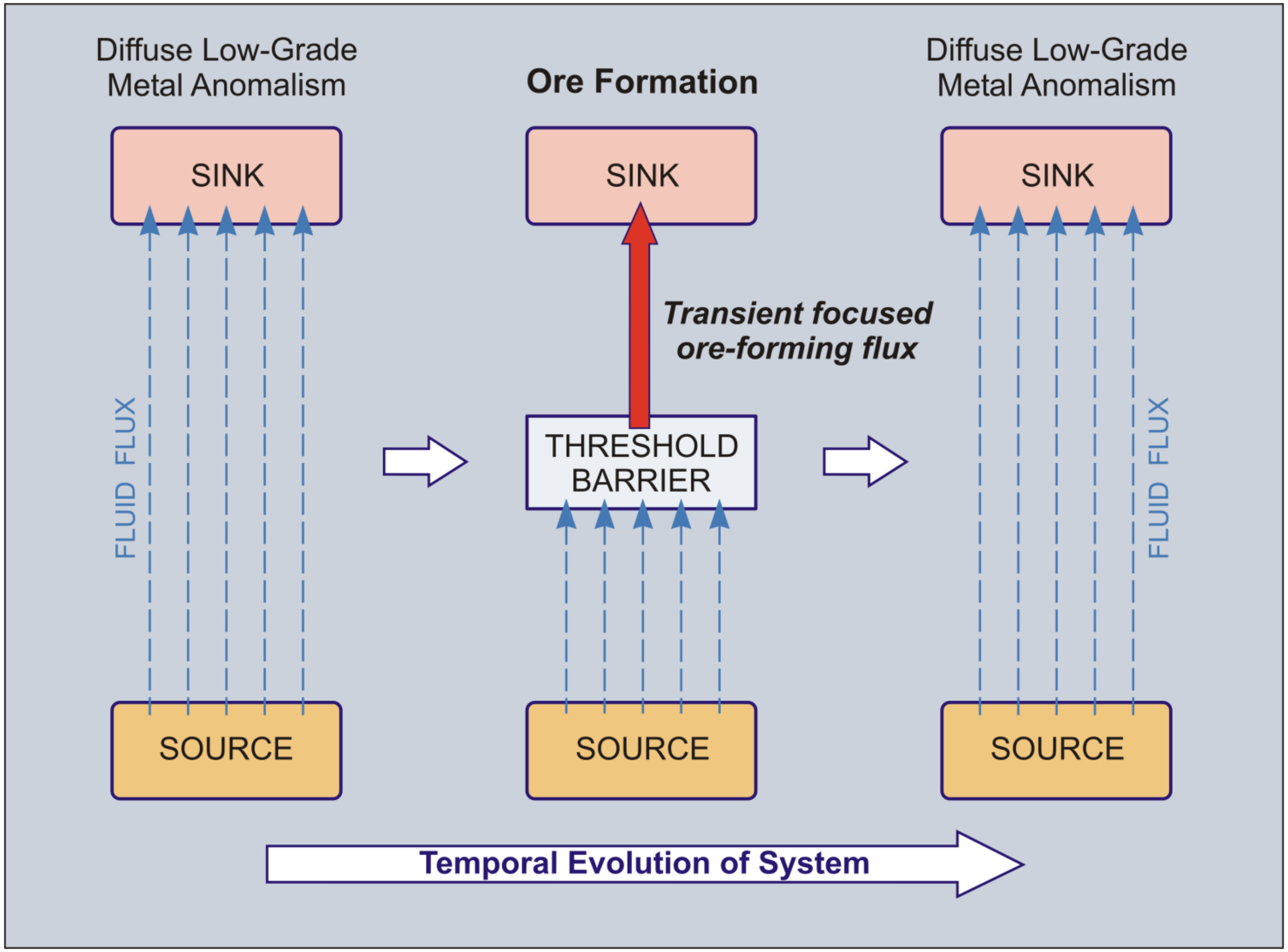

Harper & Borrok (2007)
Canada
0
450
900
kilometers
Galena-Decorah-Platteville Formations
Upper Miss Valley District Outline
Zinc in deep oil wells
Viburnum Trend Section E-F
Old Lead Belt
Bonneterre Formation
Knox Gp.
Sinking Valley
Friedensville Zinc
Timberville Zinc
East Tennessee District
Middle Tennessee District (Figure 2)
NE Arkansas
Davis
Atlantic Ocean
Gulf of Mexico
Dolomite Fronts and Associated Zinc/Lead Mineralization - Mid-Continent USA
Legend
Dolomite Front (hachures on dolomitized side of front)
Dolomitized rock behind Dolomite Front
Ore Occurrences/Significant Mineralization

Fluid Flux Organisation



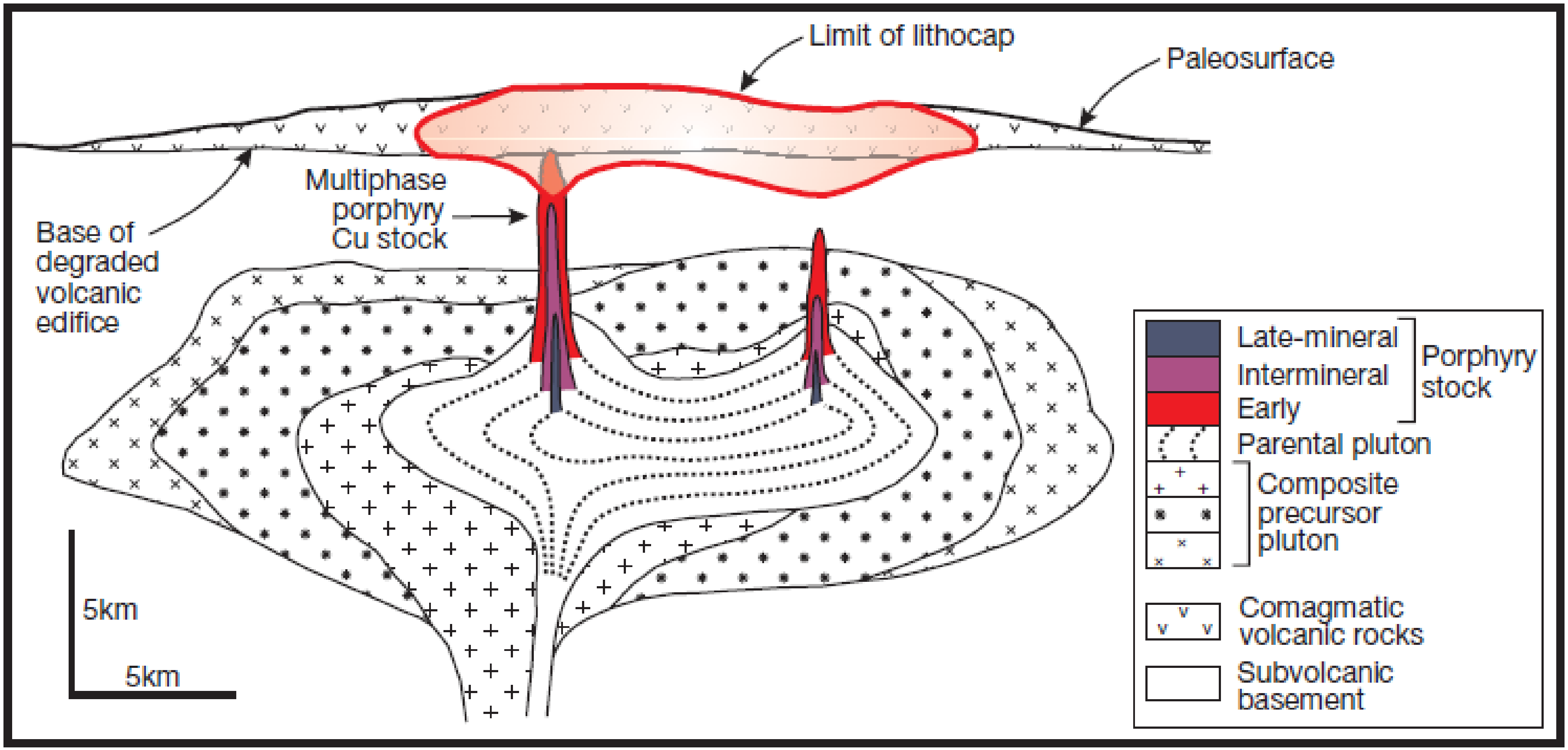
- **Concentrated Fluid Flux sufficient to form an ore deposit requires unusual self-organisation of the system (Hronsky, 2009)**
- **This in turn requires a barrier to fluid flux that produces an overpressured reservoir which is transiently ruptured in a highly focused way**
- **This organisation will only occur transiently in space and time**

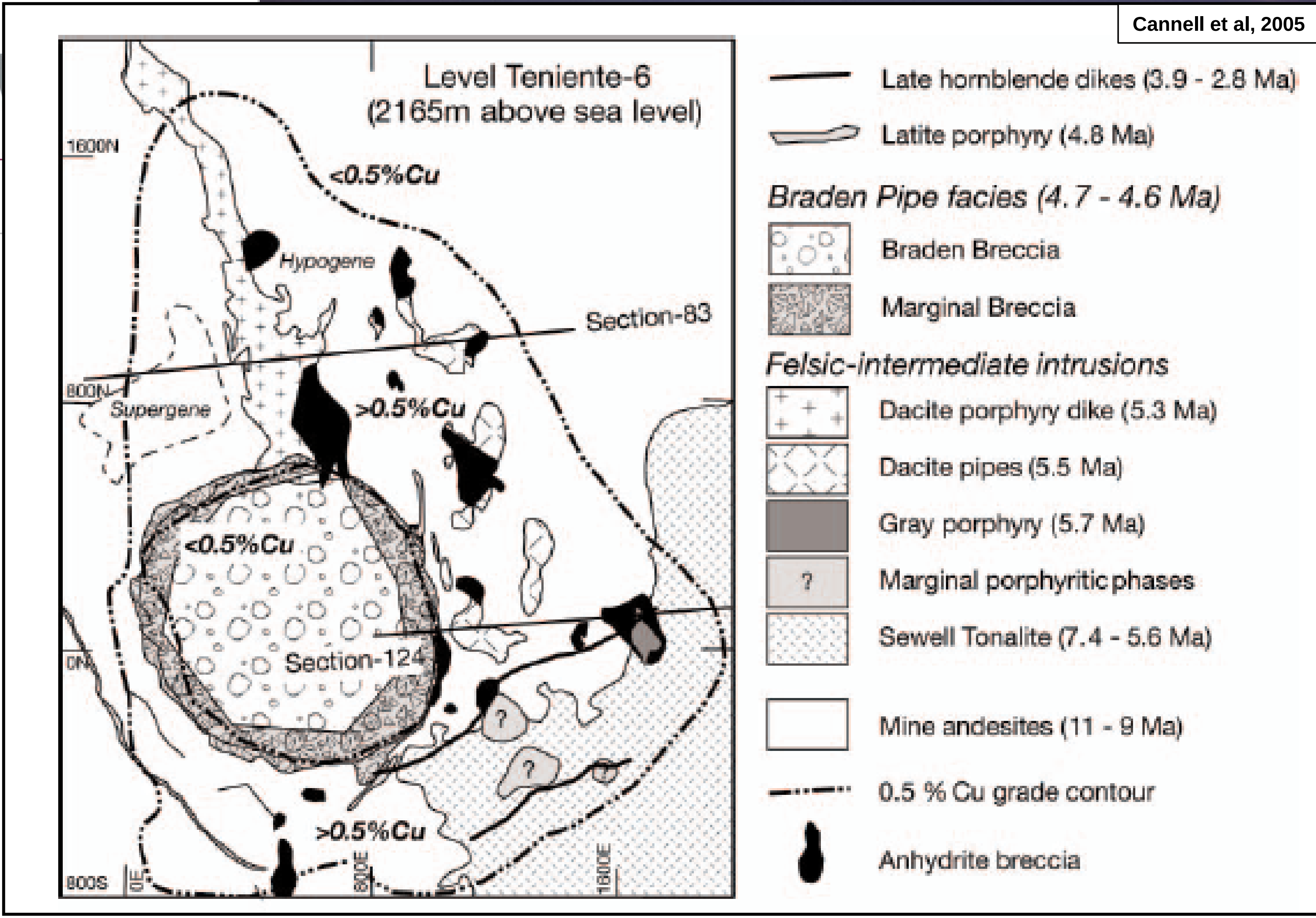
A Mineralising System Only transiently organises to form Ore



An Example: Porphyry Cu Deposits

From Sillitoe (2010)



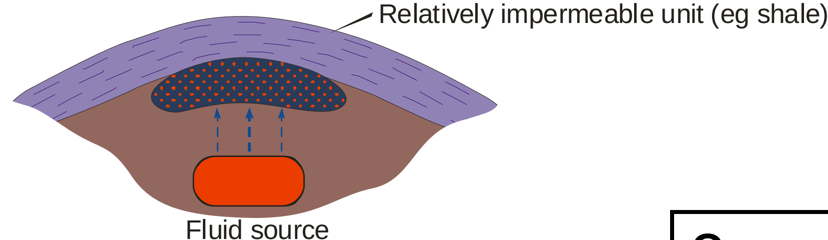


Polymictic Diatreme Breccia (Braden Breccia) terminates ore-formation at El Teniente:
This event represents failure of the underlying threshold barrier
Similar antithetic relationship between ore and diatremes documented at Kelian and Olympic Dam

WESTERN MINING SERVICES

Common Scenarios: Local Fluid-Flux Barrier and Related Overpressured Reservoir

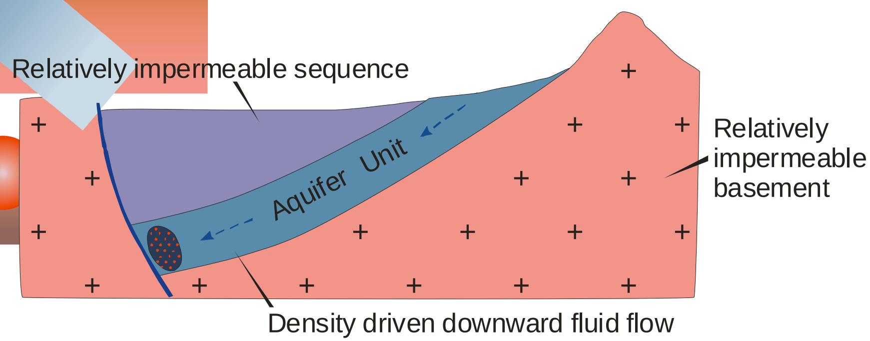
1. ANTIFORMAL SEAL



Overpressured fluid reservoir

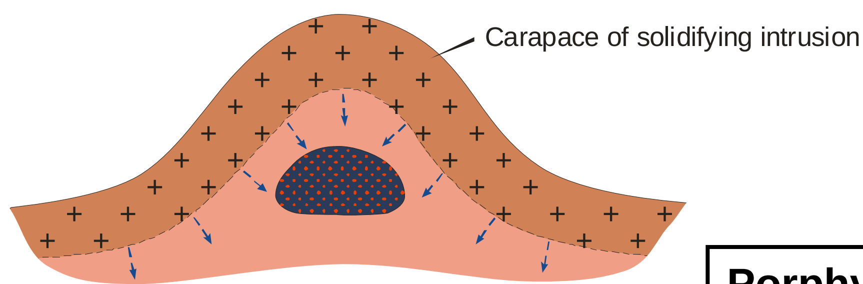
Orogenic Au deposits

2. BASEMENT HORST / BASEMENT MARGIN SEAL



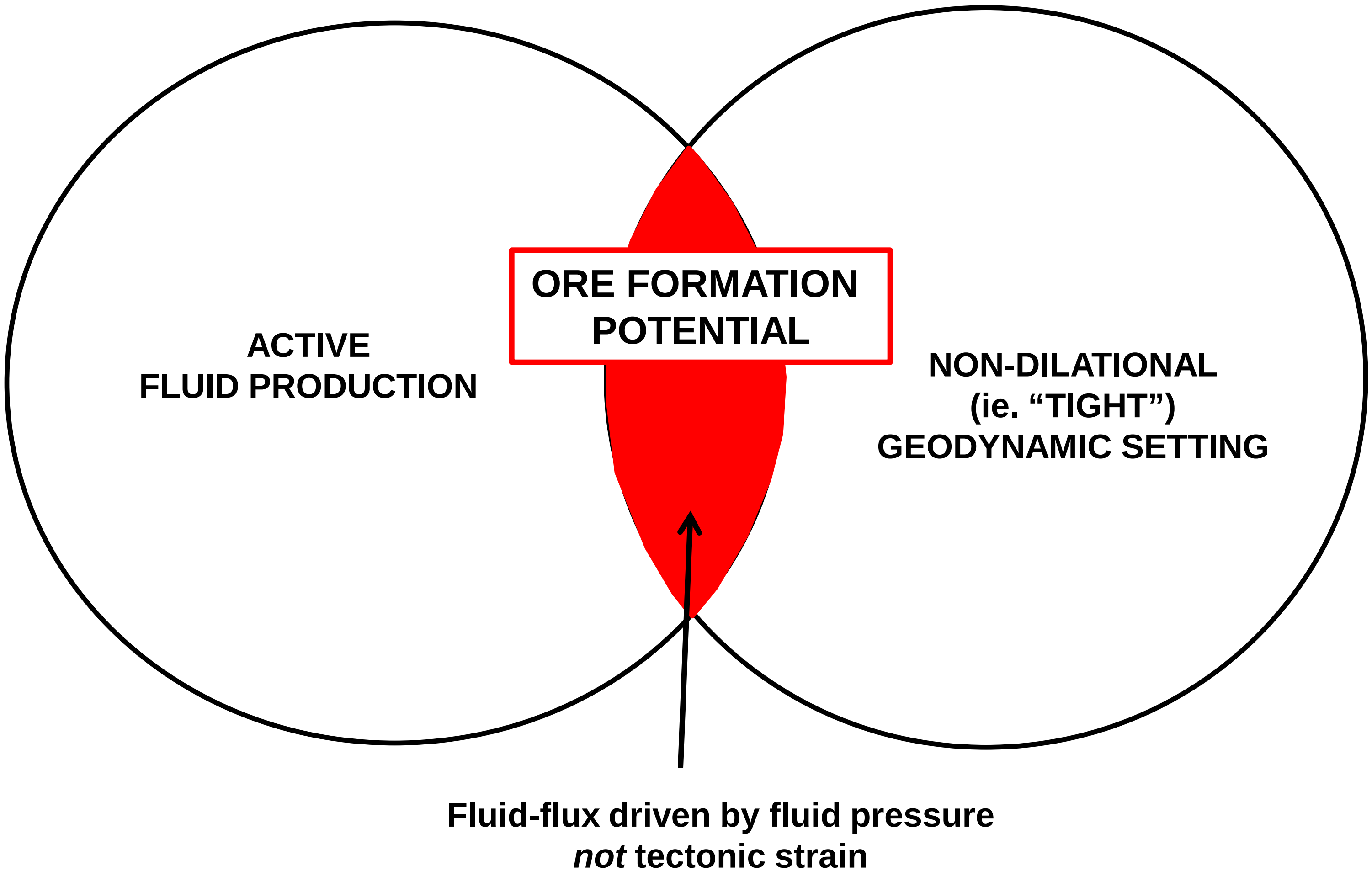
Sed Basin Base Metals/U

3. INTRUSION CARAPACE SEAL



Porphyry Cu/Mafic NiS

Physics of Ore Formation Means Only Certain, Rare Geodynamic Environments have Ore-Forming Potential



- Geodynamic settings that satisfy the constraints of ***both*** active fluid production and a non-dilational geodynamic setting are likely to be rare
- Four main scenarios:
  1. Incipient Extension: VMS, Akalic LSE Au, Komatiite NiS?)
  2. Transient Compression: Porphyry Suite deposits, Mafic Intrusion NiS
  3. Switches in Far-Field Stress (stress is transiently neutral): All?
  4. Terminal stages of an Accretionary Orogen: IRG and Orogenic Au

WESTERN MINING SERVICES

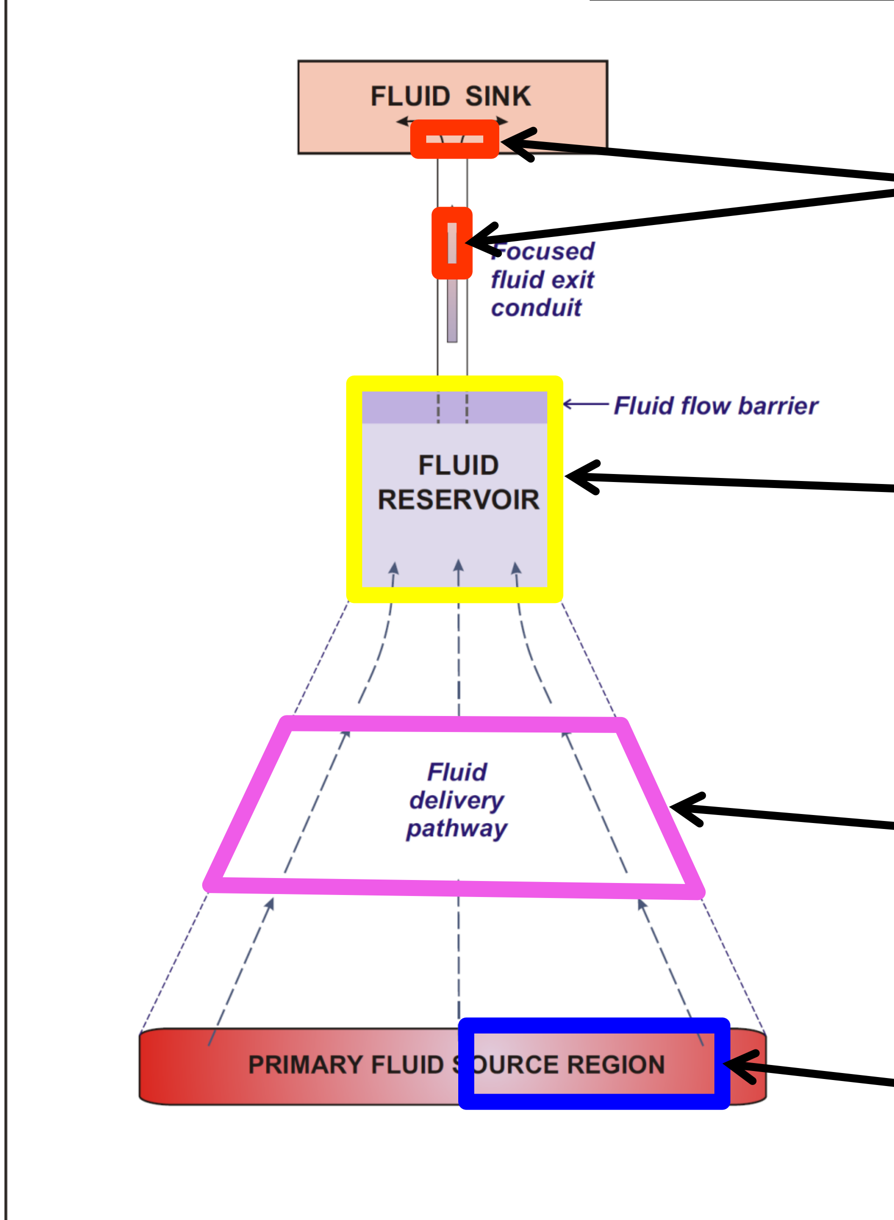
But What About Chemical Processes?

- **Much more diverse, complex and difficult to predict than fundamental physical processes**
- **Metal-bearing fluids in the upper crust encounter steep physical and chemical gradients - many potential depositional mechanisms, even within very similar mineral systems**
- **Explains why most metallogeny in upper 10km of crust**
- **Some proposed chemical mechanisms violate physical constraints (eg fluid mixing in the mesothermal environment)**
- **However, chemical processes still important and define type of mineral system and precise location of ore formation**

Mapping Chemical Processes to the Physical Mineral Systems Model

- **Key is defining a set of generic elements that represent important chemical processes but can also be related to rock volumes**
- **These rock volumes are by definition a subset of those in the Physical Mineral Systems Model**
- **Four critical elements:**
  - **1. Pre-fertilisation of the fluid source region**
  - **2. Metal/Other Critical Solute source regions**
  - **3. Fluid Fractionation Site**
  - **4. Metal Depositional Site**
- **If proxies for the rock volumes relating to these four elements can be defined, it will possible to significantly refine the generic Physical Mineral Systems Model**

Chemical Process Elements:
Subset Rock Volumes of the Generic Physical Mineral System



4. Ore Depositional Site – either in conduit or at discharge site

3. Fluid Fractionation Site (eg magma > hydrothermal fluid; silicate magma > sulphide magma) – likely to overlap Fluid Reservoir

2. Metal and/or Critical Solute (eg Cl, S) source region

1. Pre-Fertilised Fluid Source Region (eg enriched upper mantle)

Conclusion

- **A new physical-process based perspective on the Mineral Systems has significant potential benefits for both understanding ore formation and practical exploration targeting**

- **The advantage of this approach are:**

  - **Focus on most fundamental and largest scale (therefore easiest recognisable) processes ("wood not trees")**

  - **Relates all processes to a physical rock volume which can be mapped (via proxies) in our targeting frameworks**